'250

United States Department of Agriculture

Forest Service

Pacific Northwest Research Station

Research Note PNW-RN-501 March 1991

Response of Thinned White Fir Stands to Fertilization With Nitrogen Plus Sulphur

P.H. Cochran

Abstract

A single application of 200 pounds nitrogen (N) plus 33 pounds of sulphur (S) per acre to white fir (*Abies concolor* (Gord. & Glen.) Lindl.) increased periodic annual increments of basal area and volume by 1.7 $ft^2 \cdot acre^{-1} \cdot year^{-1}$ and 43 to 68 $ft^3 \cdot acre^{-1} \cdot year^{-1}$ respectively over 4- or 5-year periods. The stands become infested with budworms (*Choristoneura occidentalis* Freeman and *C. retiniana* (Walsingham)) after fertilization thereby causing increased variability in height growth. The influence of fertilization on height growth therefore was statistically significant in only one of the two stands studied. Evidence in these and other studies suggest that thinned white fir and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) respond well to N plus S on pumice and ash soils and to N on many other soils. Rates of N application higher than 200 pounds per acre are not recommended.

Keywords: Growth rates, fir —) fertilization, pine —) fertilization, budworms, managed fir stands.

Introduction

Research on the response of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) to fertilization in Oregon has been ongoing since the 1960s (Cochran and others 1979, Powers and others 1988). Fertilization with nitrogen (N) alone and in combination with sulphur (S), and phosphorus (P) has produced large increases in volume increments for many thinned stands. All three elements and their interactions produce statistically significant increases in growth of pine seedlings on pumice soils in the greenhouse (Youngberg and Dyrness 1965). Application of P and S when applied with N increased basal area growth over N alone, and all three elements in combination produced the greatest growth of basal area in one study in pole-sized ponderosa pine. Volume growth was not increased by S and P in combination with N over N alone in this study (Cochran 1978). Response of volume growth to S in the field tends to be significant, and available evidence suggests S is more important than P on pumice and ash soils (Will and Youngberg 1978).

Volume growth has been increased by fertilization as much as 75 percent over controls for ponderosa pine and 100 percent over controls for lodgepole pine for short periods. Even so, the economic benefits are questionable (Cochran 1989, Cochran and Barrett 1983, Randall 1979) on medium and low sites. White fir (*Abies concolor* (Gord. & Glend.) Lindl.) and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) pole and sawtimber stands have much higher growth rates than stands of

---

P.H. Cochran is a soil scientist, Silviculture Laboratory, 1027 NW Trenton Avenue, Bend, OR 97701.

lodgepole and ponderosa pine. The same percentage increases in volume production through fertilization for most pine stands produce much higher amounts of wood in white or grand fir stands. Loewenstein and Pitkin (1963) found that height growth of grand fir during the first growing season after N application is no different than growth before treatment. In the second growing season, though, height growth due to application of 150 pounds per acre of N is 233 percent of pretreatment growth, and height growth due to application of 150 pounds per acre N plus 150 pounds per acre of potassium (K) and 65 pounds per acre of P is 286 percent of the pretreatment growth. Scanlin and Loewenstein (1979) found that 200 pounds per acre N in the form of urea increases volume increment per tree by 23 percent in unthinned stands and 54 percent in thinned stands. Graham and Tonn (1979) found that fertilization with 200 and 400 pounds per acre of N increases diameter and height growth of grand fir over controls but that there is no difference in response between the 200- and 400-pound treatments. Shafii and Moore (1989) found that fertilization of grand fir with 200 pounds of N per acre increases average tree volume over 14 years by 14 percent in unthinned stands and 23 percent in thinned stands. Preliminary responses from some white fir fertilizer trials in California indicate 40- to 55-percent increases in volume growth rates over 3 to 5 years after application of 200 pounds per acre of elemental N (Powers 1979). Miles and Powers (1988) summarize results from 16 true fir sites in California where application rates of 200 pounds N per acre produced responses in periodic annual volume increment ranging from –16 to +70 percent over controls. Doubling the application rate increased the volume increment in only one study. Average response to treatment was 35 and 18 percent for the 200- and 400-pound application rates, respectively. In central Oregon, a 35-percent increase in growth of white fir stands would be substantial.

A white fir-grand fir species complex is recognized in the central Oregon Cascade Range (Zobel 1973). Many of the trees in Oregon and Washington, including those from the study areas of concern here, display characteristics of both species although they are referred to locally as white or grand fir. The term "white fir" is used in this report for these trees, even though some of the trees have definite grand fir characteristics. White fir occurs in nearly pure stands on about 2.5 million acres east of the Cascades in Oregon and Washington. White fir is also mixed with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), western larch (*Larix occidentalis* Nutt.), ponderosa pine, and lodgepole pine over a much larger area. Although even-aged stands of white fir are capable of high growth rates (Cochran 1979a), managers of white fir are often faced with serious disease and insect problems. When white fir is attacked by defoliating insects, such as the western spruce budworm (*Choristoneura occidentalis* Freeman) or the Modoc budworm (*C. retiniana* (Walsingham)), fertilization may limit the damage by increasing the amount of foliage produced.[1] This note reports responses of two white fir stands to applications of N plus S. One stand has pole-sized timber with some small sawtimber and the other stand is sawtimber-sized.

[1] Wickman, Boyd E.; Mason, Richard R.; Paul, H. Gene. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Manuscript in preparation. On file with: Boyd E. Wickman, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, OR 97850.

Methods of Study

Study Areas

The pole-sized stand is located at an elevation of 5,500 feet on the northwest, west, and southwest aspects of a small butte (slopes are 3 to 10 percent) in the SW1/4 NE1/4 sec. 6, T. 15 S., R. 10 E., of the Willamette Meridian about 14 miles southwest of Bend, Oregon. The soil is developing on Mazama pumice and ash 23 to 28 inches deep. A 1-inch-thick litter layer is present over an A1 horizon 2 inches deep, which is over a 7-inch-thick AC horizon and a C1 horizon containing more than 50 percent mixed material from the AC horizon and the buried profile. Bulk densities are 0.65 $Mg \cdot m^{-3}$ or less, the soil is very well drained, and none of these horizons offers any barrier to root proliferation. The natural fertility is low (table 1) and conversion of some of the nutrients to a pounds-per-acre basis makes this low fertility even more evident. The buried profile has a IIB horizon of mixed cinders and ash extending to a depth of 34 inches and IIC2 horizon consisting of about 80 percent cinders. The stand in 1979 was 46 years old at breast height (b.h.) with a basal area of 225 square feet per acre. Fifteen percent of the basal area of the stand was in other species, primarily lodgepole pine, but some ponderosa pine and a few western white pine (*Pinus monticola* Dougl. ex D. Don) also were present. These pines were being severely attacked by mountain pine beetle (*Dendroctonus ponderosae* Hopkins). Old burned tree trunks and stumps indicated that the stand originated after a fire. No understory was present but dead remnants of snowbrush (*Ceaothus velutinis* Dougl. ex Hook.) and manzanita (*Arctostaphylos patula* Green) were scattered though the stand. Site index averages 84 feet (Cochran 1979b).

Table 1—Some properties of the soils supporting the pole and saw timber stands[a]

Sample depth	pH	Extractable cations: P	K	Ca	Mg	Na	B	Organic matter	Total nitrogen	C.E.C.	Sulfate sulfur
Inches		*– – ppm – –*		*– – – cmol(+)·kg^{-1} – – –*			*ppm*	*– – Percent – –*		*cmol(+)·kg^{-1}*	*ppm*
					POLE STAND						
0-2	6.2	11	66	2.1	0.12	0.02	0.20	8.45	0.17	15.7	3.6
2-9	6.9	4	70	1.8	.13	.02	.12	3.0	.05	12.4	Trace
9-22	6.6	2	59	2.0	.28	.03	.10	1.95	.06	15.2	Trace
22-34	6.6	2	51	1.2	.23	.05	.08	1.45	.05	15.5	Trace
					SAWTIMBER STAND						
0-5	6.4	20	262	4.7	.36	.10	.25	8.09	.10	14.19	Trace
6-12	7.0	16	198	1.0	.53	.09	.12	1.96	.04	7.97	Trace
12-18	6.4	15	136	1.5	.10	.10	.22	1.74	.03	8.07	Trace

[a] Analyses were performed by the Oregon State University Soil Testing Laboratory, Corvallis, by the methods of Roberts and others (1971).

The sawtimber stand is about 5.5 miles northwest of Fort Klamath in sec. 11 and 12, T. 33 S., R. 6 E. The elevation of the area is 4,550 feet and the topography is flat. The deep, well-drained soil is forming on fine Mazama ash deposited around the outer edge of the avalanche flow from the Mazama eruption. A litter layer up to 3 inches thick is present. The loamy coarse sand A1 horizon is 5 inches thick, and the loamy sand to gravely loam AC horizon is 12 inches thick. The C horizon contains some pumice gravel and is greater than 20 inches in thickness. The bulk densities are low (0.55 to 0.65 $Mg{\cdot}m^{-3}$), no barriers to root proliferation are present, permeability is high, and the soil has low natural fertility (table 1). This stand was 100 years old at b.h. in 1981 when it was commercially thinned. Tallest tree heights were almost 100 feet, but increment borings suggested that high stand densities in the past and possible attacks by budworms have retarded height growth. Estimates of site index values from height growth after thinning indicates the site index (Cochran 1979b) of the area is about 94 feet. For the thinning, leave trees were marked and the thinning was primarily from below to a leave density of 0.3 normal. Normal stand density is defined as (Cochran and Oliver 1988):

$$\log_e(\text{trees/acre}) = 10.31 - 1.73[\log_e(\text{mean diameter})] \,. \qquad (1)$$

Thinning slash was scattered with some concentrations piled. None of the scattered slash or the slash in piles was burned.

Plot Layout and Measurements

Ten square or rectangular plots with 33-foot buffer strips were used in each stand. For the pole-sized stand, the plots were 0.2 acre; 0.4-acre plots were used in the sawtimber stand. The plots and their buffers in the pole-sized stand were thinned in summer 1980. All pines and suppressed and most intermediate fir were cut. Leave density was about 45 percent of normal. Slash was lopped and scattered, and boles of the felled trees were cut in 4-foot lengths and left on the surface. On all plots, trees were tagged at b.h., diameters were measured to the nearest 0.1 inch, and all heights were measured with poles or optical dendrometers. On each plot, two large trees, two small trees, and one intermediate-sized tree were measured with optical dendrometers for volume determinations. These trees were randomly selected from diameter distribution charts made for each plot. Total cubic-foot volume for the bole, including the stump and tip, were determined for each of these five sample trees per plot by using equations from Grosenbaugh's (1964) STX program modified to use Cochran's (1982) bark thickness model. For the sawtimber stand, Scribner board-foot volume to a 5-inch top also was determined for these sample trees. Volume equations of the form,

$$\log_e V = a + b(\log_e D) + c(\log_e H) \,,$$

were then determined by using regression techniques with the 50 trees from each area. This model was chosen because it has worked well in other studies and because it does a better job than other commonly used models of describing the relation of volume to diameter and height over a wide range of tree sizes. These

equations were then used with the diameters and heights of the additional trees to determine their volume. All these measurements were taken after the growing seasons and just before the beginning and at the end of the measurement periods. The measurement period was five growing seasons for the pole stand (growing seasons 1981 through 1985) and four growing seasons for the sawtimber stand (growing seasons 1985 through 1988).

Fertilizer Treatments

For each area, 5 of the 10 plots were randomly selected for fertilization and the remaining 5 plots served as controls. Fertilized plots received 200 pounds per acre of N and 33 pounds per acre of S. Urea (45-0-0) and ammonium sulfate (21-0-0-24) were the carriers. Fertilizer was broadcast-applied by hand in late October before the first growing season in the measurement period. The weather was cold and 3 inches of wet snow was on the ground when fertilization occurred in the pole stand. Weather was cool and snow was forecast as fertilizer was applied in the sawtimber stand. Buffer strips of the fertilized plots received fertilizer at the same application rate as the plots.

Design and Analyses

The studies in both areas have a completely randomized design. Each area was analyzed separately because the measurement periods were of different lengths and had only one common growing season. Previous experience in pine studies indicated that periodic annual increments (PAIs) for plots were linearly related to initial plot basal area (BA) if the range of basal areas was not great. Further, the random choice of plots for fertilization in both areas resulted in a narrow range of basal areas for the fertilized plots; a density-fertilizer interaction would probably be difficult to detect even if it occurred. Therefore the model,

$$Y = b_0 + b_1(BA) + b_2F ,$$

was used to test the hypotheses that PAIs of volume, basal area, mean diameter, and height (Y) did not change with fertilization (F). In the model, F is a dummy variable equal to 1 for fertilized plots and 0 for control plots.

Budworm Infestations

The presence of budworms was not noticed during plot establishment in either stand. Visits to the plots during the subsequent growing seasons indicated, however, that budworms were present in numbers sufficient to cause noticeable defoliation. No formal estimates were taken of population densities or the amount of defoliation, but infestations became serious enough to cause top damage. The pole stand appeared to suffer more top damage, but noticeable top damage also occurred on some trees in the sawtimber stand.

To obtain some measure of budworm damage to tops, ratios of average height of all trees to site tree height were calculated for each plot at the start of the study. Site tree height is the height of the tallest tree on a 0.2-acre plot or the average height of the two tallest trees on a 0.4-acre plot. Next, undamaged heights of the site trees for plots in the pole stand were estimated for the end of the study period by using the equations of Cochran (1979b). Ratios of the actual average heights of all trees divided by the estimated heights of the site trees at the end of the period (assuming no top damage had occurred to the site trees) were then estimated for each plot. Less damage was apparent in the sawtimber stand than in the pole stand, and the site trees seemed unharmed. The ratios of the average height of all trees to height of the site trees therefore were calculated from actual values at the end of the period. The number of trees involved in calculating these ratios remained the same through the period. The assumption is made that the ratio of heights of a given number of trees to the heights of the site trees remains constant when top damage is absent in managed stands as they grow (Dahms 1983). If the ratio of a set number of heights divided by the calculated height of the site trees or the ratio of a set number of heights divided by the height of undamaged site trees were lowered during the study period because of a reduction in height growth of the nonsite trees, the change in these ratios could serve as an index to top damage by budworms.

Yield Comparisons with Pines

Volume increments for studies in ponderosa and lodgepole pine stands on soils developing from Mazama pumice and ash are available from other studies. The pine increments were compared with the increments from these white fir stands after adjustment to a common initial basal area.

Results

Initial Plot Conditions

Stocking levels in the pole stand averaged 45 percent of normal density at the beginning of the study. Basal area ranged from 84 to 175 square feet per acre, mean diameters ranged from 6.2 to 11.6 inches, average heights ranged from 29.7 to 54.2 feet, and lowest and highest plot volumes were 1,694 and 3,895 cubic feet per acre (table 2).

Initial stocking levels in the sawtimber stand averaged about 40 percent of normal density. Plot basal areas ranged from 81.7 to 146.9 square feet per acre, mean diameters ranged from 12.4 to 16.9 inches, average heights ranged between 72.1 and 89.7 feet, cubic-foot volumes ranged from 2,314 to 5,121 cubic feet per acre, and board-foot volumes ranged from 9,239 to 22,530 (table 3). These statistics are initial statistics for the trees that lived through the study period.

Mortality

In winter 1980-81, four trees suffered snow damage on plots in the pole stand and were cut the following spring. No trees died during the 5-year period once the first growing season started. Eight out of 339 trees died on plots in the sawtimber stand during the 4-year measurement period; four died on plot 2 (a fertilized plot with few trees [table 3]), plots 6 and 10 each lost one tree, and two trees were lost on plot 9. Increments were calculated as if these trees never existed, and they are not shown in tables 2 and 3.

Table 2—Some statistics for the pole stand in spring 1981, the beginning of the study

Treatment	Plot	Mean d.b.h.	Average height	Trees/ acre	Basal area	Volume	Site index
		Inches	*Feet*		*Ft²/acre*	*Ft³/acre*	*Feet*
Fertilized	1	10.8	54.2	240	151.5	3895	86.6
	2	9.3	46.1	275	130.1	3048	83.5
	7	7.8	35.2	335	110.0	2759	83.1
	8	8.0	41.1	435	150.9	3532	84.5
	10	9.2	46.7	330	151.2	3143	77.9
Average		9.0	35.4	323	138.7	3275	83.1
Control	3	6.2	29.7	400	83.8	1694	83.6
	4	11.6	49.3	240	174.8	4377	91.6
	5	9.3	45.4	280	130.9	2856	77.0
	6	8.4	40.8	335	130.2	2780	84.6
	9	10.4	51.8	195	113.8	2818	83.2
Average		9.2	43.4	242	126.7	2905	84.0

Table 3—Some statistics for the sawtimber stand in spring 1985, the beginning of the study

Treatment	Plot	Mean d.b.h.	Average height	Trees/ acre	Basal area	Volume	Scribner scale
		Inches	*Feet*		*Ft²/acre*	*Ft³/acre*	*Bd. ft. volume*
Fertilized	1	14.8	86.8	97.5	115.7	4220	19,178
	2	16.9	89.7	52.5	81.7	3128	15,666
	5	15.1	82.6	87.5	108.6	3787	16,861
	8	13.4	72.1	107.5	104.7	3424	14,526
	10	14.0	72.9	105.0	112.8	3741	16,302
Average		14.8	80.8	90.0	104.7	3660	16,507
Control	3	13.2	74.3	77.5	73.2	2314	9,239
	4	14.2	75.2	85.0	93.8	3030	12,595
	6	14.1	79.0	122.5	146.2	4443	22,530
	7	14.7	83.1	100.0	117.1	4048	17,450
	9	12.4	79.3	157.5	146.9	5121	22,049
Average		13.7	78.2	108.5	115.4	3791	16,773

Growth Rates

Subtracting the appropriate initial plot values (tables 2 and 3) from the final plot values (tables 4 and 5) and dividing by the number of growing seasons produces the corresponding PAIs for mean diameter, average height, basal area, and volume (tables 6 and 7). When these plot PAIs were used with the corresponding initial plot basal areas (tables 2 and 3) in the regression model to determine the influence of fertilizer, results between the two stands differed somewhat. Values for the fertilization coefficient in the model (table 8) show that for the pole stand, fertilization increased cubic volume PAI by 43 ft^3·acre-1·$year^{-1}$ and basal area PAI by 1.8 ft^2·$acre^{-1}$·$year^{-1}$. These increases are significant at the 10-percent level, or lower, of probability (table 8). PAIs for mean diameter and average height were not significantly changed by fertilization. Except for mean diameter, all the PAIs differed significantly with initial basal area.

For the sawtimber stand, fertilization increased cubic volume PAI by 68 ft^3·$acre^{-1}$ ·$year^{-1}$, Scribner board-foot volume PAI by 357 board feet·$acre^{-1}$·$year^{-1}$, basal area PAI by 1.7 ft^2·$acre^{-1}$·$year^{-1}$, average height PAI by 0.3 ft/year, and the PAI for mean diameter by 0.1 inch/year. All the determined PAIs were significantly increased by fertilization (table 8). PAIs of mean diameter and average height decreased significantly as initial basal area increased, but PAIs for cubic-foot volume, board-foot volume, and basal area were not related to initial basal area.

Ratios of Average Height to Height of Site Trees

The low periodic annual height increments for the pole stand (table 6) indicate that budworms reduced the height growth for both the fertilized and nonfertilized plots. Height PAIs should have been greater than 1.0 foot per year. Even though the average for the height PAIs is slightly higher for the fertilized plots, the differences were not significant at the 10-percent level of probability. For the pole stand, ratios of average height to height of the site trees in 1980 ranged from 0.61 to 0.76 and averaged 0.68 for the plots receiving fertilizer. These ratios for the control plots ranged from 0.56 to 0.8 and averaged 0.70. During the study period, these ratios decreased to an average of 0.6 for both the control and fertilized plots. Although no formal statistical tests were performed, it is evident that there was no difference in the change of these ratios with treatment. For the sawtimber stand, there was no real difference in the ratios with treatment or time. The average of these ratios at both the start and end of the period was 0.81 for the control plots and 0.80 for the fertilized plots.

Comparisons of Fir and Pine Volume Increments

Thinned pine stands generally have lower basal areas than thinned fir stands. Therefore, growth rates for thinned pine stands are expected to be lower than fir stands (fig. 1). The lodgepole pine stand (stand 1, fig. 1; table 9) was fertilized with 600 pounds N per acre, 300 pounds P per acre, and 99 pounds S per acre. The ponderosa stand (stand 2, fig. 1) was fertilized with 200 pounds N per acre, 100 pounds P per acre, and 33 pounds S per acre. When the PAIs for volume are adjusted to a common basal area of 80 square feet per acre, yields of nonfertilized fir stands are about twice as high as the non fertilized pine stands. Percent increases in volume PAI with fertilization were higher for the pine stands but actual volume PAIs were higher for the fir (table 9).

Table 4—Some statistics for the pole stand in fall 1985, 5 growing seasons after treatment

Treatment	Plot	Mean d.b.h.	Average height	Trees/ acre	Basal area	Volume
		Inches	*Feet*		*Ft^2/acre*	*Ft^3/acre*
Fertilized	1	12.0	58.7	240	189.2	26,538
	2	10.6	50.3	275	170.1	24,226
	7	8.8	37.7	335	140.9	20,492
	8	8.9	43.3	435	186.4	28,584
	10	10.1	49.7	330	184.3	26,264
Average		10.1	47.9	323	174.2	21,221
Control	3	6.9	31.5	400	105.2	16,350
	4	12.5	53.0	240	205.0	26,202
	5	10.1	47.5	280	155.8	21,563
	6	9.4	43.6	335	159.8	23,032
	9	11.2	53.8	195	134.3	19,054
Average		10.0	45.9	242	152.0	21,240

Table 5—Some statistics for the sawtimber stand in fall 1988, 4 growing seasons after treatment

Treatment	Plot	Mean d.b.h.	Average height	Trees/ acre	Basal area	Volume	Scribner
		Inches	*Feet*		*Ft^2/acre*	*Ft^3/acre*	*Bd. ft.*
Fertilized	1	16.2	92.6	97.5	139.4	5267	25,702
	2	18.4	94.4	52.5	97.1	3816	19,554
	5	16.6	87.2	87.5	131.5	4675	22,064
	8	14.6	76.4	107.5	124.6	4246	19,229
	10	15.2	76.0	105.0	133.0	4530	16,302
Average		16.2	85.3	90.0	125.1	4507	20,570
Control	3	14.3	78.6	77.5	86.5	2822	12,133
	4	15.3	79.4	85.0	109.1	3649	16,553
	6	14.8	81.6	122.5	146.2	5031	22,530
	7	15.4	85.9	129.8	129.8	4630	21,446
	9	13.1	81.4	157.5	146.9	5121	22,049
Average		14.6	81.4	108.5	123.7	4251	18,942

Table 6—Periodic annual increments for the pole stand over the 5-year measurement period

Treatment	Plot	Mean d.b.h.	Average height	Basal area	Volume
		In/year	*Ft/year*	*$Ft^2 \cdot acre^{-1} \cdot year^{-1}$*	*$Ft^3 \cdot acre^{-1} \cdot year^{-1}$*
Fertilized	1	0.25	0.9	7.5	310
	2	.3	.8	8.0	300
	7	.2	.5	6.2	225
	8	.2	.4	7.1	259
	10	.2	.6	6.6	241
Average		.2	.7	7.1	267
Control	3	.15	.2	4.3	144
	4	.2	.7	6.0	300
	5	.2	.4	5.0	189
	6	.2	.6	5.9	222
	9	.2	.4	4.1	172
Average		.2	.5	5.1	206

Table 7—Periodic annual increments for the sawtimber stand over the 4-year measurement period

Treatment	Plot	Mean d.b.h.	Average height	Basal area	Volume	Scribner scale
		In/year	*Ft/year*	*$Ft^2 \cdot acre^{-1} \cdot year^{-1}$*	*$Ft^3 \cdot acre^{-1} \cdot year^{-1}$*	*Bd. $ft \cdot acre^{-1} \cdot year^{-1}$*
Fertilized	1	0.4	1.45	5.9	262	1631
	2	.4	1.2	3.8	172	972
	5	.4	1.1	5.7	222	1301
	8	.3	1.1	5.0	206	1176
	10	.3	.8	5.0	197	1205
Average		.3	1.1	5.1	212	1257
Control	3	.3	1.1	3.3	127	723
	4	.3	1.1	3.8	155	989
	6	.2	.7	3.4	147	914.5
	7	.2	.7	3.2	145.5	1004
	9	.2	.5	3.5	162	1013
Average		.2	.8	3.4	147	929

Table 8—Summary statistics for the analysis of covariance model Y = $b_0 + b_1$ (BA) + b_2 (F) used to test the effect of fertilization[a]

Summary statistics by stand	Dependent variables (periodic annual increments): Cubic foot volume[b]	Basal area[b]	Average height[b]	Mean diameter[b]	Scribner bd. ft. volume[b]
Pole stand:					
Regression coefficients—					
b_0	13.7	2.53	-0.12	0.16	—
b_1	1.51 (<0.01)	0.02 (0.01)	.0046 (0.04)	.00015 (0.50)	—
b_2	43.4 (0.07)	1.78 (<.01)	.13 (0.27)	.034 (0.68)	—
R^2	0.77	.80	.53	.28	—
Sy·x	31 $ft^3 \cdot acre^{-1} \cdot year^{-1}$	.66 $ft^2 \cdot acre^{-1} \cdot year^{-1}$	.16 ft/year	.04 in/year	—
Sawtimber stand:					
Repression coefficients—					
b_0	72.66	2.24	1.56	0.44	315.81
b_1	0.68 (0.30)	0.011 (0.66)	-0.007 (0.06)	-.002 (<0.01)	5.58 (0.17)
b_2	68.11 (<.01)	1.709 (<.01)	.29 (0.06)	.114 (<0.01)	357.11(0.01)
R^2	.77	.74	.59	.87	.65
Sy·x	22.5 $ft^3 \cdot acre^{-1} \cdot year^{-1}$	.60 $ft^2 \cdot acre^{-1} \cdot year^{-1}$	.2 ft/year	.03 in/year	162.4 bd. ft.

[a] Dependent variables are PAIs of volume, basal area, average height, and mean diameter. BA is basal area at the start of the period, and F is a dummy variable equaling 1 for fertilized plots and 0 for the control plots.
[b] Values in parentheses are p-values from the hypothesis test that the regression coefficient equals 0.

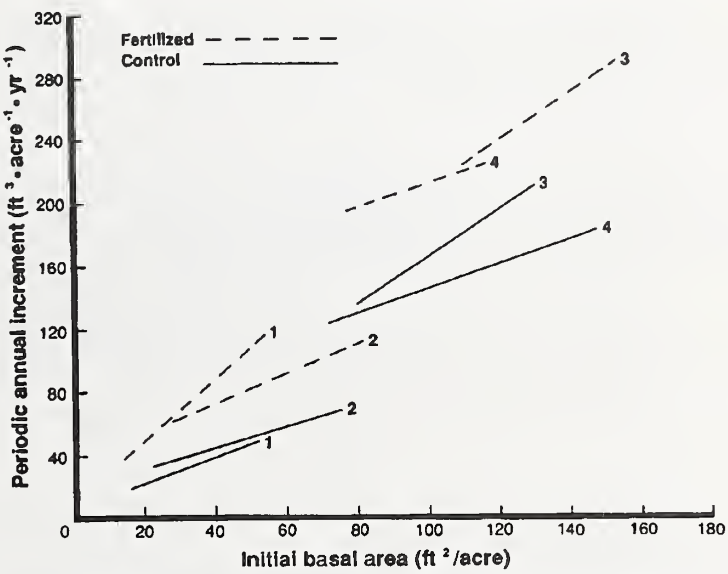

Figure 1—Periodic annual volume increments as a function of basal area at the start of the measurement period for the first 4- or 5-year period after application. Numbers 1 through 4 indicate four different stands. Stand 1 is a lodgepole stand (Cochran 1989) fertilized with 600 pounds N plus 300 pounds P and 90 pounds S per acre. Stand 2 is a ponderosa pine stand fertilized with 200 pounds N plus 100 pounds P and 33 pounds S per acre. Stand 3 is the pole-sized white fir stand, and stand 4 is the sawtimber white fir stand.

Table 9—Periodic annual volume increments over the first 4- or 5-year periods after treatment corresponding to an initial basal area of 80 square feet per acre

Species	Periodic annual volume increments by treatment		Increase of fertilized stands over control
	Control	Fertilized	
	$Ft^3 \cdot acre^{-1} \cdot year^{-1}$	*$Ft^3 \cdot acre^{-1} \cdot year^{-1}$*	*Percent*
Lodgepole pine	72	166	131
Ponderosa pine	71	111	56
White fir poles	135	178	32
White fir saw timber	127	195	54

Discussion

Stands of white fir can be thinned from below to stocking levels equivalent to 0.5 normal or even less without losing much potential growth or any usable growth in the absence of serious insect or disease problems (Cochran and Oliver 1988). Fertilization in combination with thinning produces more volume and much larger tree sizes than fertilization without thinning or thinning alone (Shafii and Moore 1989). When the costs and benefits of fertilization are being considered in a management decision, the advantages of harvesting the same amount of volume with fewer but larger stem sizes should be taken into account.

Fertilization, when the response is positive, accelerates the rate of movement by a stand toward a target size. Direct effects due to increased tree nutrition have lasted at least 4 or 5 years in these studies, and the indirect effects due to increased tree sizes will continue as the stands develop. Just how far fertilization can project these stands forward in time will not be determined until the studies are remeasured at 4- or 5-year intervals at least once or twice more. Basal area PAIs (table 8) of fertilized plots show average increases of 1.8 $ft^2 \cdot acre^{-1} \cdot year^{-1}$ for the pole stand and 1.7 $ft^2 \cdot acre^{-1} \cdot year^{-1}$ for the sawtimber stand. Multiplying these increases in PAIs by the length of the study period produces 9 extra square feet of basal area for the pole stand and 6.8 square feet of basal area for the sawtimber stand. Dividing these increases by the average basal area PAIs for the control plots (tables 6 and 7) provides a crude estimate of 2 years for the length of time these stands were projected ahead by fertilization during the first study period.

There is no conclusive evidence that fertilization reduced the amount of top damage by budworms in either stand; however, fir stands are subject to much higher populations of budworms than were found in either of these stands during the study thus far. At higher population levels of budworm, a reduction in top damage might occur with fertilization.

The response to fertilization at any given site is related to several factors including the amount of available soil water, the balance of nutrients, and the rates at which nutrients become available. Unfortunately, no simple test is available that allows good predictions of potential responses to fertilization across a range of sites (Miles and Powers 1988).

The acreage of white or grand fir has expanded considerably with the exclusion of fire on lands historically occupied by ponderosa pine. Comparisons of growth rates for healthy fir and pine stands might lead to the conclusion that this replacement of ponderosa pine by fir will actually result in increased wood production. It is very possible, however, that fir stands on these lower sites will not remain healthy through a rotation. The idea that fir should be managed on ponderosa sites and that fertilization can be used as a management tool to partially compensate for lower amounts of soil water should be discouraged.

Conclusions

Fertilization of thinned white or grand fir stands on pumice and ash soils with 200 pounds of N plus 33 pounds of S per acre will produce substantial increases in volume production in the absence of serious insect and disease problems. No simple diagnostic tests are available to indicate how fir stands will respond on other soils, but evidence from studies in California and Idaho indicate substantial responses to N applications at rates of 200 pounds per acre will occur on many soils. Higher levels of N application are not recommended. Duration of response and the possible role of fertilization in combating serious insect and disease problems encountered in many fir stands are not yet determined.

Literature Cited

Cochran, P.H. 1978. Response of a pole-sized ponderosa pine stand to nitrogen, phosphorus, and sulfur. Res. Note PNW-379. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Cochran, P.H. 1979a. Gross yields for even-aged stands of Douglas-fir and white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-263. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Cochran, P.H. 1979b. Site index and height growth curves for managed even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-252. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Cochran, P.H. 1982. Estimating wood volumes for Douglas-fir and white fir from outside bark measurements. Forest Science. 28(1): 172-174.

Cochran, P.H. 1989. Growth rates after fertilizing lodgepole pine. Western Journal of Applied Forestry. 4(1): 18-20.

Cochran, P.H.; Barrett, James W. 1983. Fertilization of ponderosa pine—responses and costs. In: Robson, Thomas F.; Standiford, Richard B., eds. Management of the eastside pine type in northeastern California; Proceedings of a symposium; 1982 June 15-17, Susanville, CA. SAF 83-06. Arcata, CA: Northern California Society of American Foresters: 66-69.

Cochran, P.H.; Oliver, William W. 1988. Growth rates for managed stands of white fir. In: Schmidt, Wymann C., comp. 1988. Proceedings: Future forests of the mountain West: a stand culture symposium; 1986 September 29-October 3; Missoula, MT. Gen. Tech. Rep. INT-243. Ogden, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 197-200.

Cochran, P.H.; Youngberg, C.T.; Sternbrenner, E.C.; Webster, S.R. 1979. Response of ponderosa pine and lodgepole pine to fertilization. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Proceedings, forest fertilization conference; 1979 September 25-27; Union, WA. Institute of Forest Resources Contrib. 40, Seattle: University of Washington: 89-94.

Dahms, Walter G. 1983. A growth simulation model for lodgepole pine in central Oregon. Res. Pap. PNW-302. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 22 p.

Graham, Russell T.; Tonn, Jonalea R. 1979. Response of grand fir, western hemlock, western white pine, western larch, and Douglas-fir to nitrogen fertilization in northern Idaho. Res. Note INT-270. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Grosenbaugh, L.R. 1964. STX-FORTRAN 4 program for estimates of tree population from 3P sample tree measurements. Res. Pap. PSW-13. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 46 p.

Loewenstein, Howard; Pitcan, Franklin H. 1963. Response of grand fir and western white pine to fertilizer applications. Northwest Science. 37(1): 23-30.

Miles, Scott R.; Powers, Robert F. 1988. Ten-year results of forest fertilization in California. Earth Resources Monograph 15. San Francisco, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 77 p.

Powers, Robert F. 1979. Response of California true fir to fertilization. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds., Proceedings, forest fertilization conference: 1979 September 25-27; Union, WA. Institute of Forest Resources Contrib. 40. Seattle: University of Washington: 95-101.

Powers, Robert F.; Webster, Steve R.; Cochran, P.H. 1988. Estimating the response of ponderosa pine forests to fertilization. In: Schmidt, Wymann C., comp. Proceedings—future forests of the mountain West: a stand culture symposium; 1986 September 29-October 3; Missoula, MT. Gen. Tech. Rep. INT-243. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 219-225.

Randall, R.M. 1979. Some financial implications of 5-year fertilizer trials in ponderosa pine. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Proceedings, forest fertilization conference; 1979 September 25-27; Union, WA. Institute of Forest Resources Contrib. 40. Seattle: University of Washington: 231-233.

Roberts, S.; Vodrasku, R.U.; Kauffman, M.D.; Gardner, E.H. 1971. Methods of soil analysis used in the soil testing laboratory at Oregon State University Agriculture Experiment Station Spec. Rep. 321. Corvallis, OR: Oregon State University. 39 p.

Scanlin, D.C.; Loewenstein, H. 1979. Response of inland Douglas-fir and grand fir to thinning and nitrogen fertilization in northern Idaho. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Proceedings, forest fertilization conference; 1979 September 25-27; Union, WA. Institute of Forest Resources Contrib. 40. Seattle: University of Washington: 82-88.

Shafil, Bahman; Moore, James A. 1989. Effects of nitrogen fertilization on growth of grand fir and Douglas-fir stands in northern Idaho. Western Journal of Applied Forestry. 4(2): 54-57.

Will, G.M.; Youngberg, C.T. 1978. Sulfur status of some central Oregon pumice soils. Soil Science Society of America Journal. 42(1): 132-134.

Youngberg, C.T.; Dyrness, C.T. 1965. Biological assay of pumice soil fertility. Soil Science Society of America Proceedings. 29(2): 182-187.

Zobel, Donald B. 1973. Local variations in integrating *Abies grandis-Abies Concolor* populations in the central Oregon Cascades: needle morphology and periderm color. Botanical Gazette. 134(3): 209-220.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 591-001/40028

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208-3890

NATIONAL
FORESTS
1891 1991

U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208